

OPERATIONAL PLANNING FOR CALIFORNIA WATER SYSTEM

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ABSTRACT: A detailed river basin simulation model has been developed by the California Department of Water Resources to simulate the combined operation of two major water project systems in California, namely the Central Valley Project (CVP), operated by the U.S. Bureau of Reclamation, and the State Water Project (SWP), operated by the California Department of Water Resources. Each agency operates upstream reservoirs in Northern California to serve local water users as well as to provide for exports of water to more arid Central and Southern California regions. Much of this export water flows through the Sacramento-San Joaquin Delta, which has become a major focal point for water policy controversy in California. The size and complexity of this combined CVP-SWP system of reservoirs and conveyance facilities is such that proposed changes in water use or development of future water project facilities may involve analyzing or changing numerous system or operational constraints. The simulation model developed provides the necessary flexibility to analyze a wide range of assumptions for various planning alternatives. A major feature of the model is to allow proper sharing of Sacramento-San Joaquin Delta inflows between the CVP and SWP to meet Delta water quality outflow requirements as well as respective project export needs. Many model features are incorporated so the model can be used to analyze the effect of various alternatives of future surface reservoirs, changes in cross Delta transfer proposals, proposed groundwater reservoirs, and many other proposed system changes. The range of model capabilities is described along with some example studies.

INTRODUCTION

About 70% of the total streamflow in the State of California originates north of the latitude of Sacramento while 80% of the ultimate water requirements lie south of that line (1). In addition, most of the State's runoff occurs during the winter and spring, when needs are minimal. Further, the variation in runoff from year to year causes problems whenever a sequence of dry years occurs. These contrasts, coupled with environmental considerations and a projected increase in demand for water create the need for effective water resources planning and development in California.

To overcome California's water distribution problems, two major water projects were constructed, namely the Central Valley Project (CVP), built first by the US Bureau of Reclamation, and the State Water Project (SWP), built later by the State Department of Water Resources. These projects comprise a system of dams, reservoirs, canals, tunnels, pumping plants,

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FIG. 1.—Major Features of State Water Project and Central Valley Project

and power plants designed to serve multi-objectives of flood control, recreation, power generation, and water conservation.

Both projects consist of major storage facilities in Northern California, with the principal objective to store winter surplus runoff for summer irrigation in the Sacramento Valley and to provide water for export to central and southern areas of the state. Export water released from northern California project reservoirs flows down to the Sacramento-San Joaquin Delta where CVP and SWP pumping plants receive the water and export it south through the CVP's Delta Mendota Canal and the SWP's California Aqueduct. The general locations of the CVP and SWP facilities in California are shown in Fig. 1. The characteristics of the storage facilities that are operated as part of the simulation model are summarized in Table 1.

Although each project operates its upstream reservoirs separately, the releases from the upstream reservoirs are intermixed in the Sacramento River and the Sacramento-San Joaquin Delta (Delta) where southern exports are made by each project. Inflows to the Delta must be shared between the two projects in the Delta. In addition, minimum Delta water quality standards established by the California State Water Resources Control Board must be maintained. To share water for Delta outflow and Delta exports, the two agencies recently proposed a Coordinated Operating Agreement (COA), which is in the final states of negotiation. The

TABLE 1.—Major CVP and SWP Storage Facilities (1)

Project (1)	Reservoir (Dam) (2)	Capacity (TAF) (3)	Purpose (4)	50-year average annual inflow (5) (TAF) (5)	Year completed (6)
CVP	Shasta Lake	4,552	W, P, F, R ^a	5,756	1945
	Clair Engle Lake	2,448	W, P, R	642	1962
	Whiskeytown Lake	241	W, P, R	255	1963
	Folsom Lake	1,010	W, P, F, R	2,620	1956
	New Melones	2,400	W, P, F, R	1,117	1979
SWP	Lake Oroville	3,538	W, P, F, R	4,429	1968
	Silverwood Lake	75	S, R	—	1971
	Lake Perris	132	S, R	—	1973
	Pyramid Lake	171	S, P	—	1974
	Castaic Lake	324	W, S, P, R	—	1973
Joint	San Luis	2,039	S, P, R	—	1967

^aW = Water Supply; P = Power; F = Flood Control; R = Recreation; S = Reregulatory Storage.

Note: 1 TAF = 1.23×10^6 m³.

features of the proposed COA have been incorporated in the model (4).

This paper describes the computer simulation model developed for use in California water resources planning studies by the Department of Water Resources for the operation of the CVP-SWP system. The "HEC-3 Reservoir System Analysis for Conservation" model developed by the US Corps of Engineers' Hydrologic Engineering Center (HEC) in Davis, CA has been adopted as a basic tool for reservoir releases and channel routings. The original HEC-3 model has been extensively modified and enhanced to provide more modeling flexibility and features and to account for the special characteristics of the CVP-SWP system. The model accounts for proper sharing of Sacramento River and San Joaquin River Delta inflows by the CVP and SWP and provides unique capabilities for conducting studies not possible with the original HEC-3 model. The model developed is now called the DWR Planning Simulation Model and is being used for many planning studies by the California Department of Water Resources to test possible future additions or changes to the CVP-SWP system.

GENERAL MODEL DESCRIPTION

The DWR Planning Simulation Model is a generalized computer planning model for California's Central Valley and the CVP-SWP project systems. It is a simulation program designed to operate the CVP-SWP system on a monthly time basis for purposes of water supply, recreation, instream flow augmentation, and hydroelectric power generation. The program is quite flexible in that changes for almost any configuration of surface reservoirs, groundwater reservoirs, river diversions, power generating plants, pumping plants, and conveyance facilities can be incorporated by changes in data entry to the program rather than modifying the model. In addition, various operating criteria such as reservoir op-

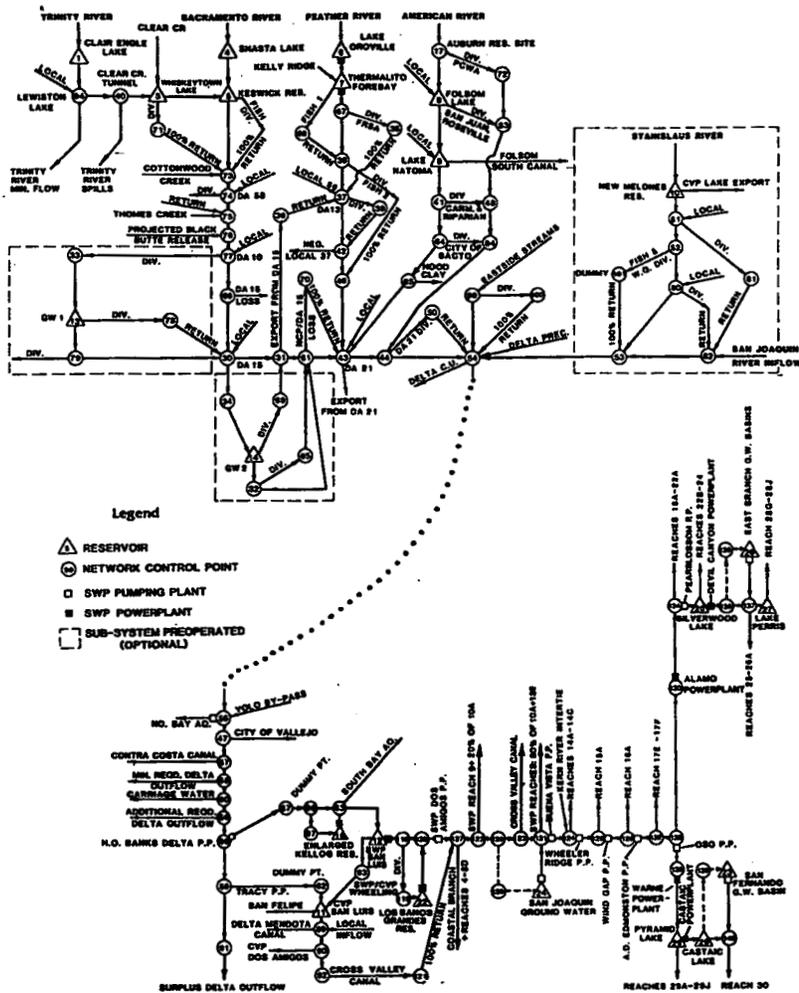


FIG. 2.—DWR Planning Simulation Model Network Representation

erating rules or Delta outflow requirements can be easily changed by data entry as well.

The DWR Planning Simulation Model represents the actual CVP-SWP system by a network of control points depicting surface reservoirs, groundwater reservoirs, river diversions, tributary stream inflow points, pumping plants, and power generating plants. The control points are connected by links representing river and canal reaches. The schematic representation of the CVP-SWP system is shown in Fig. 2.

Inflow Data.—For a typical planning simulation study, the system inflows to the reservoirs and downstream tributary inflows for the model are based on the historic hydrology for the period 1922–1978. The historic hydrology for this period has been adjusted to reflect present or

future land use and "nonproject" reservoir operations. Therefore, studies are based on the historic hydrology that has been modified to reflect conditions at a future level.

This adjustment to the historic hydrology is developed using the Department's Consumptive Use and Depletion Study Models (2). In a present level study, historic flows are adjusted to reflect the effect of present land use patterns, and for a future level study such as year 2000, the historic flows would be adjusted for estimated year 2000 land use patterns. Thus, a typical planning simulation study would simulate the operation of the CVP-SWP system for a continuous 57-yr period using the historic hydrologic inflows adjusted to the desired level of development such as year 2000.

In addition to using adjusted historic inflows, the Department has applied a stochastic hydrology model (3) to provide monthly multi-station synthetic inflows, which are directly compatible for input to the DWR Planning Simulation Model. These generated flows provide different but equally likely sequences of possible future hydrologic inflows for use in certain types of planning studies.

Reservoirs.—The physical characteristics of surface reservoirs are defined by data input in terms of elevation versus storage, surface area, and outlet capacity relationships. Groundwater reservoirs that are operated as part of the CVP-SWP system are also treated as simple reservoirs. In addition, reservoir power plant characteristics are entered to the model if simulation of power generation or energy consumption is to be included.

Surface reservoirs are operated to make releases to meet various criteria such as minimum downstream channel flows and required diversions at selected downstream control points. Further additional releases are made to evacuate space for required flood control levels or to satisfy

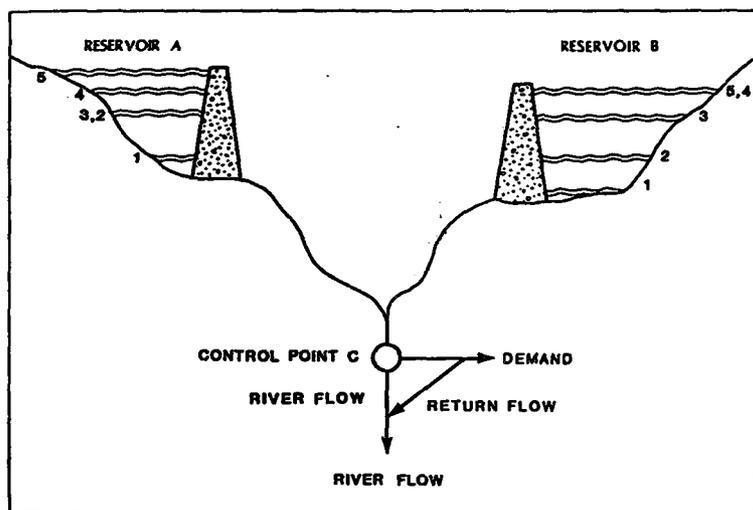


FIG. 3.—Level Allocation of Two Parallel Reservoirs

specified monthly reservoir power generation requirements.

Five "target storage levels" are used for each monthly time period to define the operating rules for the CVP and SWP reservoirs upstream of the Sacramento-San Joaquin Delta (Delta). The program could easily be changed to allow more target storage levels to be used. These levels permit an integrated operation of CVP and SWP upstream reservoirs to meet commonly served downstream control point demands.

Fig. 3 shows how the reservoir target levels work. If both Reservoir A and Reservoir B start out full at level 5, the program determines the amount of reservoir release to satisfy the demand at the commonly served Control Point C. In this example, there is no space in Reservoir B allocated between level 5 and level 4. Therefore, the demand at Control Point C will be met from Reservoir A until Reservoir A reaches level 4. Then both reservoirs will be drawn down equally by percentage of storage space remaining between level 4 and level 3. When both reservoirs reach level 3, releases will occur from Reservoir B only until Reservoir B reaches level 2 as there is no space allocated between levels 3 and 2 in Reservoir A. The process is continued until the reservoirs are depleted. If desired, one or both of the reservoirs could be set not to meet any demand at Control Point C. It is also important to note that these storage target levels can be changed each month.

Instream Flow Requirements.—Control points that do not represent reservoirs are used to establish instream river or canal demands. At each point a maximum allowable flow and a minimum required flow may be specified. Maximum flow constraints may represent a channel capacity or a pumping plant capacity. Minimum flow requirements may represent minimum fish, water quality, or navigation flows. These maximum and minimum flow requirements can be varied by month. Releases from the surface reservoirs are controlled either to meet the minimum downstream requirements or not to exceed maximum downstream criteria.

Diversions.—Reservoir releases are also made so as to meet required downstream river or canal diversions. Diversions are also made at reservoirs themselves. Diversions may be varied for each month of the simulation, or they may be set on a 12-month pattern or they may be constant each month. A river diversion can also be set as a function of streamflow or reservoir storage. Special model features which allow diversions to vary depending on the water year type and allow them to increase or decrease with time will be examined later in more detail.

Many diversions represent the lumped irrigation demands along the reach of a river or canal and are specified at a control point. Return flows from irrigation diversions are expressed as a percentage of the irrigation diversion. The percentages can be varied each month on a 12 month pattern. Therefore, the return flow percentages in winter months, for example, could be different than those in summer months. Several special program features were also added to the model to account for certain unique diversions in the CVP-SWP system, which will be covered later in separate sections.

KEY MODEL ASSUMPTIONS

The simulation model for the CVP-SWP network is unique in that the model must account for the interactive and coordinated operation of the

CVP and SWP systems. Recently, the Bureau of Reclamation and the Department of Water Resources developed a proposed Coordinated Operating Agreement (COA) to govern the operation of the two projects. The COA defines how the Department and the Bureau propose to share responsibility for Delta outflow and determine the proper share of water available for each agency for export from the Delta. The provisions of the proposed COA agreement for sharing Delta surpluses and Delta outflow requirements have been incorporated into the DWR Planning Simulation Model.

CVP-SWP Coordinated Operation.—The joint studies between the Department and the Bureau, which led to the proposed COA, utilized what has been referred to as a "first-in-time" approach. In order to perform simulation studies in which future SWP or CVP facilities are added, it is necessary to determine the effect or adjustment that the new facilities would have on the COA Sharing Formula. For example, if a new SWP facility were added to the system, the yield of the CVP system must not be adversely affected, and therefore the operational sharing formula must be adjusted accordingly. The sharing formula must also be adjusted to account for changes in upstream hydrology with time. To accomplish this, it was necessary to develop three versions of the DWR Planning Simulation Model called Model A, Model B, and Model C.

Delta Outflow and Consumptive Use.—The CVP-SWP system is operated so as to provide minimum Delta outflows and maintain Delta water quality standards specified by the State Water Resources Control Board in D-1485 (6). Many of the D-1485 standards are specified as water quality standards at certain locations in the Delta. The Department has conducted separate model studies to determine the minimum flows to meet the required quality standards.

Model C incorporates these standards as minimum required monthly flows (diversion at Control Point 58 in Fig. 2). These standards are based on tables that account for the year type determined by the Four-River Index, the month of the year, the San Joaquin River Inflow, and the previous month inflow. The Four-River Index is the sum of the natural flows in Sacramento, Feather, Yuba and American Rivers.

In addition to minimum outflow, the model determines the carriage water (diversion at Control Point 60 in Fig. 2) or additional required Delta outflow that increases in proportion to the amount of export pumping in the Delta.

The Delta consumptive use and Delta channel depletions are based on the cooperative study conducted in 1981 by the Department and the Bureau of Reclamation. These values, which are based on estimates of historic use, are entered as data for various levels of development.

The Model simulation actually proceeds in two cycles each month. In the first cycle all of the Delta demands below Control Point 54 (Fig. 2) are set to zero. Monthly inflows are read by the program and project reservoirs upstream of the Delta are operated to meet minimum local instream demands and to make flood control releases. This establishes the minimum release required by each system reservoir. The program then computes the total flow arriving at the Delta (Control Point 54 in Fig. 2) after meeting upstream diversions.

Next, the program sums the SWP demands starting at the southern end of the California Aqueduct working up to the Dos Amigos Pumping Plant (Control Point 120 in Fig. 2). The program calculates the maximum and minimum SWP delivery required at the Dos Amigos Pumping Plant for that month. The minimum SWP demand at Dos Amigos would be the amount necessary to meet all the monthly delivery demands south and to meet specified minimum monthly target levels in the SWP southern California reservoirs. The maximum SWP demand at Dos Amigos would be not only the amount necessary to meet all the delivery demands, but also that amount required to fill the remaining space in all the SWP southern reservoirs. Maximum deliveries may be constrained by aqueduct pumping plant or channel capacities.

San Luis Reservoir is a joint facility operated by the CVP and the SWP. Storage space is divided into the CVP San Luis portion and the SWP San Luis portion in the model. This is actually achieved by splitting San Luis into two separate reservoirs. The minimum required SWP Delta Pumping Plant export demand is therefore the sum of the minimum SWP Dos Amigos demand plus any necessary amount to achieve the SWP San Luis target storages plus the amount required to meet the South Bay demand (diversion at Control Point 63 in Fig. 2). The maximum possible Delta Pumping Plant export is the sum of the maximum possible SWP Dos Amigos demand plus the amount necessary to fill the remaining storage space in SWP San Luis plus the South Bay export demand. The Delta Pumping Plant exports may also be limited by canal capacity, the Delta Pumping Plant capacity itself, or by legal constraints such as the May-July export curtailment to meet D-1485.

In the same manner, the program computes the CVP maximum and minimum demands south of the Delta. The maximum CVP Delta export is often limited by the Tracy Pumping Plant capacity or the Delta Mendota Canal reach capacity between the Tracy Pumping Plant and O'Neill Forebay. The Tracy Pumping Plant exports may be further limited in May and June as required by D-1485.

At this point, the program enters the COA sharing subroutine. The subroutine is used to determine each agency's share of required Delta outflow to meet D-1485 standards including carriage water, which is the additional outflow required due to Delta export pumping. The subroutine will also determine the amount of unstored flow or surplus Delta inflow each agency is entitled to export.

Each project will export its share of surplus Delta flows up to the maximum desired (i.e., where there is space in San Luis and there is Delta export pumping capacity available). If there is not enough surplus Delta inflow to meet one or both of the agencies minimum required Delta exports, then additional upstream reservoir releases will be made by the affected agency in the second simulation cycle.

If an additional SWP release is required from Oroville Reservoir (as determined from the analysis after the first simulation cycle), this amount is added to the Oroville release used in the first simulation cycle. The Oroville release is therefore fixed in the second simulation cycle as the amount necessary to meet SWP share of instream flow requirements (from the first cycle) plus the additional amount necessary to meet the SWP share of Delta outflow and SWP Delta exports. With the SWP Oroville

Reservoir release fixed in the second cycle, it is not operated as a "system reservoir" to meet downstream control point demands in the second cycle. The CVP reservoirs are left to meet all remaining diversions, Delta outflow requirements, and Delta exports and balance among themselves according to the method shown in Fig. 3. In this manner, the simulation model is able to operate each project properly to meet its share of Delta outflow and its share of Delta exports.

TYPES OF DWR PLANNING SIMULATION STUDIES

There are basically three types of planning studies that can be performed with the DWR Planning Simulation Model. The formulation of the study objectives and accompanying assumptions determine how the model is used and the type of study to be performed.

Yield Studies.—Model studies are often run to determine the SWP water supply firm yield with a given set of facilities assuming certain operating criteria at a present or future level of water development. Yield studies are run to demonstrate the system performance through the most severe critical dry period (1928–1935) in recent history (1922–1978) and have been used as a basis for contractual agreements between the Department and SWP contractors. For DWR planning studies, firm yield is defined as the maximum SWP water deliveries that can be achieved each year without imposing more than a 50% agricultural deficiency in any one year or more than a 100% agricultural deficiency in any seven-year period. The calculation of SWP firm yield does not normally include deliveries to the Feather River Service Area. Firm yield studies are run without delivering any surplus water. A SWP delivery level is determined through several trial runs so that about 850 thousand acre-feet (TAF) of storage remains in Lake Oroville at the end of the critical period, which is normally May 1928–October 1934. In addition, there is normally about 530 TAF of combined remaining storage in the SWP San Luis and SWP Southern California terminal reservoirs. Several trial computer runs are often required so as to adjust the assumed operating criteria to maximize the firm yield. Reservoir target levels or rule curves for surface storage reservoirs south of the Delta and SWP delivery deficiency patterns can often be adjusted so as to minimize Delta outflow to the ocean during the critical period.

Average Annual Delivery Studies.—Recently, there has been increasing interest in measuring expected future SWP system performance in terms of average annual deliveries. For these types of studies, model simulations are normally performed using the historic 57-yr period from 1922–1978 at an adjusted future level of hydrologic development such as year 2000. Running average annual delivery studies necessitates operating the system in a manner which the planner feels would be most realistic or consistent with actual project operations. The simulation study may be conducted several ways.

For example, once the SWP firm yield is determined for a given set of facilities and operating assumptions, the system may be operated to deliver the firm yield plus various amounts of surplus in years when surplus water is available. With the DWR Simulation Model, this is achieved by first estimating surplus delivery amounts for each water year

type (based on the Four-River Index). The wet year surplus delivery estimate may be 1 MAF ($1.23 \times 10^9 \text{ m}^3$) in above normal years it may be 800 TAF ($9.84 \times 10^8 \text{ m}^3$) in below normal years it may be 500 TAF ($6.15 \times 10^8 \text{ m}^3$) and in the dry years it might be 200 TAF ($2.46 \times 10^8 \text{ m}^3$). These amounts become only initial estimates, which are specified in scheduled surplus patterns from March 1–February 28. The monthly wet year surplus pattern plus the firm yield pattern represents the maximum annual delivery pattern which the system will try to achieve. Groundwater recharge is in addition to surplus deliveries and may have a higher delivery priority. As the hypothetical 57-yr simulation proceeds, the model determines the water year type based on the Four-River Index.

On March 1, the proper surplus delivery pattern associated with the water year type is initially selected and the simulation proceeds through September. At the end of September, the model checks the SWP system carryover storage in Oroville, SWP San Luis, and the SWP terminal storage reservoirs to determine if the combined storage is within a specified target range. If the carryover storage is within this target range, the simulation continues to a following year. If the SWP carryover storage on September 30 is too high or too low the difference is calculated. The model then goes back to March 1, adjusts the surplus delivery amount, and then simulates the system operation again from March–September thereby delivering more or less surplus or taking larger deficiencies as necessary to achieve a SWP system storage within the target range. The simulation then continues from October 1–February 28 on the revised surplus pattern.

In addition to scheduled surplus deliveries, the model may be set to deliver unscheduled Delta surplus water up to the monthly maximum or wet year pattern of scheduled surplus demands. Unscheduled surplus is delivered in a month when: (1) All Delta requirements have been met and there is Delta surplus flow; (2) all scheduled SWP demands including scheduled surplus are met; (3) groundwater recharge demands are met; (4) all reservoirs south of the Delta are full; and (5) Delta Pumping Plant capacity and aqueduct conveyance are still available. These unscheduled surplus deliveries will be made only up to the wet year or maximum pattern amount allowed for that month. Using these rules, the SWP operation is such that it is delivering as much surplus every year as possible, up to a maximum pattern (or wet year pattern), while maintaining a target carryover storage in the SWP each year, which would be consistent with a reasonable operation.

Under these assumptions, however, the model may be delivering too much surplus water in years when high local runoff occurs in the Southern California watersheds. Therefore, changes are now being incorporated so that the model will calculate a Southern California wetness index called a Five-River Index based on the natural flows at the San Joaquin, Kings, Kaweah, Tule, and Kern Rivers. The user can then establish delivery restrictions based on the Five-River Index that will limit SWP deliveries in wet years. Thus, the Four-River Index will be used as a first estimate to define SWP possible surplus deliveries. However, surplus SWP deliveries may be limited by the Southern California Five-River Index in wet years. Downward adjustments to surplus deliveries can also be made to ensure minimum annual target carryover storages in the SWP

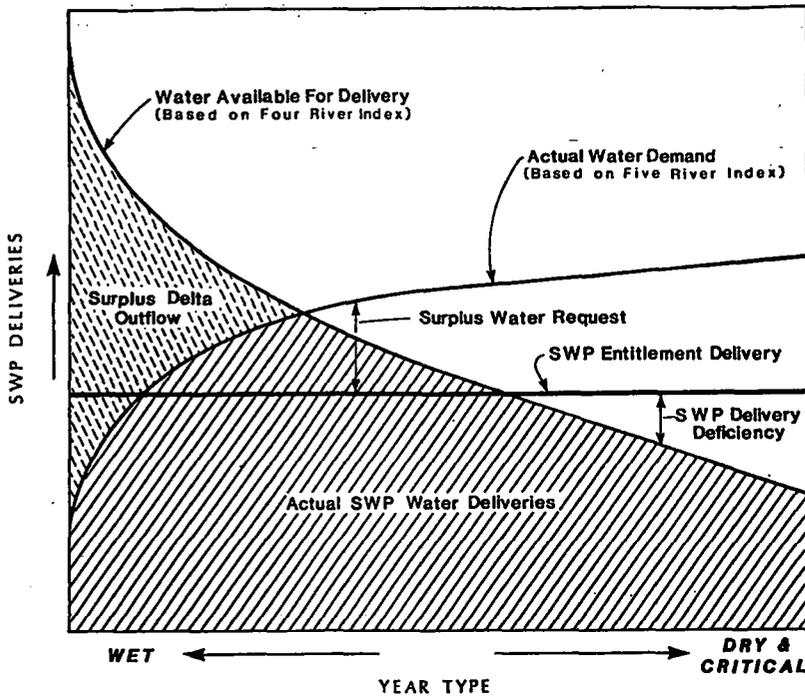


FIG. 4.—State Water Project Deliveries versus Water Year Type

surface reservoirs. Fig. 4 represents how SWP deliveries as a function of water year type may be envisioned.

The criteria for SWP target carryover storage requirements may be easily changed. Presently, the SWP is operated to deliver surplus water when the projected SWP September 30 carryover storage is greater than about 3.14 MAF ($3.86 \times 10^9 \text{ m}^3$), 2.4 MAF ($2.95 \times 10^9 \text{ m}^3$) in Oroville Reservoir and 740 TAF ($9.10 \times 10^8 \text{ m}^3$) in project reservoirs south of the Delta. A typical set of SWP target carryover storages used in planning model studies is shown in Table 2. It should be noted that these numbers are subject to change.

The table shows that in a dry year if the September 30 carryover storage falls below 1.6 MAF ($1.917 \times 10^9 \text{ m}^3$) the model will go back to March 1 and adjust the SWP demands so as to impose a 25% agricultural deficiency from March 1–February 28 of the following year. As indicated further in Table 2, if the SWP carryover storage on September 30 falls below 900 TAF ($1.11 \times 10^8 \text{ m}^3$), 50% SWP agricultural deficiency will be taken and if below 800 TAF ($9.84 \times 10^8 \text{ m}^3$), a 60% agricultural plus a 10% municipal and industrial deficiency is taken.

Future studies may demonstrate that other SPL target carryover storages would be more desirable. This may be especially true if more storage facilities are added to the SWP system or included in a future level study that could provide carryover storage not presently available.

TABLE 2.—SWP Target Carryover Storage Requirements*

Year type (1)	Maximum TAF (2)	Minimum TAF (3)
Wet	3,100	3,050
Above normal	3,100	3,050
Below normal	3,100	3,050
Dry	3,100	1,600
Critical (25% Ag Def.)	3,100	900
Critical (50% Ag Def.)	3,100	800
Critical (60% Ag & 10% M&I Def.)	3,100	600
Critical (80% Ag & 30% M&I Def.)	3,100	500

*Combined end-of-September carryover storage in Oroville, SWP San Luis, and offstream surface storage reservoirs and in Southern California, not including groundwater storage south of the Delta.

Note: 1 TAF = 1.23×10^6 m³.

In many planning studies, the future SWP contractor delivery requests exceed the SWP yield with an assumed set of envisioned future facilities. Therefore, these studies are run so as to deliver the SWP yield plus any additional amount up to the level of estimated contractor requests while maintaining specified annual SWP carryover storages. In these studies the "surplus water" deliveries may actually represent delivery of entitlement requests.

Dynamic Planning Studies.—Planning study descriptions so far have been confined to simulations using historic hydrology adjusted to a fixed level of future development such as year 2000 or 2020 level. Therefore, in a 50-yr hypothetical simulation, it is assumed that time is held constant, and the results of the study depict the expected project performance at a given level of development over 57 yr of repeated historical sequence.

However, in some instances, it may be desirable to simulate the system over a planning horizon from the present to a future date such as 2015. During this period, depletions upstream of the Delta will be increasing each year, thereby reducing Delta inflows with time. In addition, contractor demands south of the Delta will be increasing and demands for surplus will vary depending on the wetness of the year. The amount of water available for surplus deliveries will depend on variable unknown future water supplies. In a dynamic planning study, it may be necessary to analyze the likely operation of a groundwater basin south of the Delta from the present to year 2015.

The simulation model can be set to increase upstream depletions and control point diversions representing contractor deliveries each year in a desired pattern. In addition, the model will meet surplus water demands depending on: (1) The Four-River Index; and (2) the SWP system reservoir carryover storage required. Thus, the simulation will proceed where contractor demands will be steadily increasing as well as fluctuating depending on the wetness of the year while at the same time, upstream depletions will be increasing.

Further, the model has the capability of bringing on line future facilities such as a new reservoir or enlarged pumping plant at a specified

year into the simulation. For example, if a dynamic study was started in 1985, the model could automatically begin operation of a new upstream reservoir in the tenth year or 1995. The new reservoir would necessarily have to go through the process of initial filling just as it would under real time operation. In fact, the model could be specifically used for reservoir filling studies.

Dynamic planning studies lend themselves especially well to the use of stochastic hydrologic input. Synthetic inflows can now be generated and used as input to the simulation model. The Department recently applied a stochastic hydrology model for this purpose which can generate multi-site stochastic inflows for the DWR Planning Simulation Model.

As previously mentioned, the historic hydrology for the period 1922 through 1978 is adjusted to a future level of development for most planning studies. The river diversions and water use upstream of the Delta are determined from the consumptive use and depletion studies and are then used as input to the simulation model. Therefore, these upstream diversions are unique each month and are to some extent a function of the rainfall and year type.

EXAMPLES OF DWR PLANNING STUDIES

Upstream Storage Reservoirs.—Yields and average annual deliveries of storage facilities have been estimated for proposed future reservoirs in Northern California. They are Cottonwood, enlarged Shasta, Auburn, and Marysville. In case of Marysville, the results can be summarized in Table 3. Fig. 5 displays the cumulative frequency distributions of average annual deliveries for the no project or base condition and three alternatives.

Offstream Storage and Integrated Groundwater Simulation.—The Department has conducted several studies evaluating various offstream storages proposed along the California Aqueduct. Various reservoir sizes at Control Points 16 and 22 labeled Enlarged Kellogg and Los Banos Grandes Reservoir are used for these offstream storage studies.

In addition, the simulation model can accommodate the presence of integrated groundwater projects as part of the SWP system south of the Delta. Integrated groundwater projects are treated as simple reservoirs in the model network. The conjunctive operation of the groundwater projects provide that storage releases from Oroville and San Luis Reservoirs as well as Delta surpluses are used for recharge. One or more groundwater projects as represented on the network diagram in Fig. 2 may be simulated.

TABLE 3.—Yield and Annual Delivery for Marysville

Size of proposed Marysville TAF (m ³) (1)	Increment firm yield above base system TAF/yr (m ³ /yr) (2)	Increment average annual delivery above base system TAF/yr (m ³ /yr) (3)
400 TAF (4.92 × 10 ⁸)	68 (8.36 × 10 ⁸)	89 (1.09 × 10 ⁸)
640 TAF (7.89 × 10 ⁸)	155 (1.91 × 10 ⁸)	192 (3.21 × 10 ⁸)
916 TAF (1.13 × 10 ⁹)	218 (2.68 × 10 ⁸)	261 (3.21 × 10 ⁸)

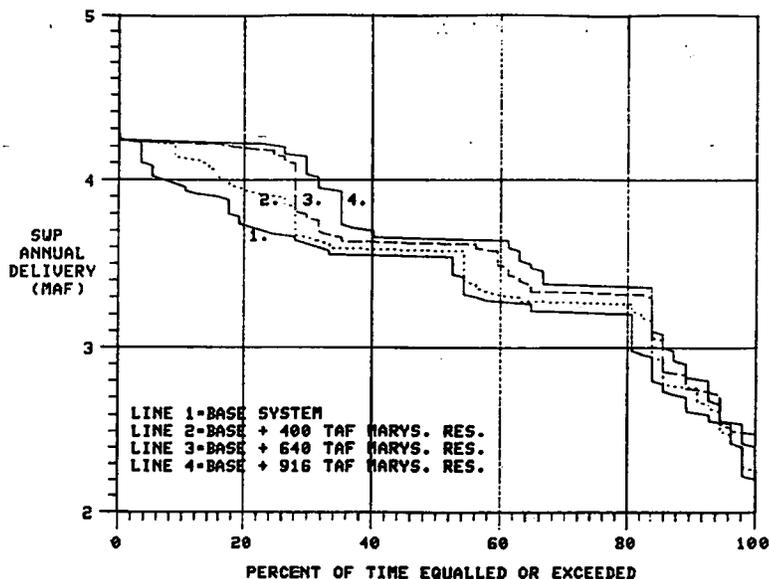


FIG. 5.—Cumulative Frequency of SWP Deliveries with Alternate Sizes of Proposed Marysville Reservoir

The recharge pattern for the groundwater basins may be set as a constant amount or it may be varied on a twelve month pattern. In the same manner, groundwater withdrawals may be assumed as constant or variable each month. Depending on the water year type and the status of the surface reservoirs, the model will assume either recharge or withdrawals occur beginning on March 1 and continuing through the following February. The model was designed to assume that when withdrawals are necessary, they must begin in March because the withdrawal rates may be quite limited. The rationale for this is that under actual SWP operation, project operators could not wait until late in the summer to determine that groundwater withdrawals would be needed because it would be too late to provide much delivery assistance as the groundwater withdrawal rates are so limited.

Groundwater projects south of the Delta can also be viewed as "local" groundwater facilities that are not fully integrated as part of the SWP system. In these instances, the local groundwater projects simply are viewed by the model as additional water demands on some specified pattern, and the operation of the "local" groundwater reservoirs themselves are not simulated.

Conveyance and Pumping Plant Limitations.—The various physical capacities of the California Aqueduct and SWP pumping plants are described in terms of input data to the simulation model. Therefore, it is quite easy to design studies under a wide range of assumptions to analyze the conveyance capacities of the aqueduct system to pinpoint reaches or pumping plants which are potentially constraining. Using the study

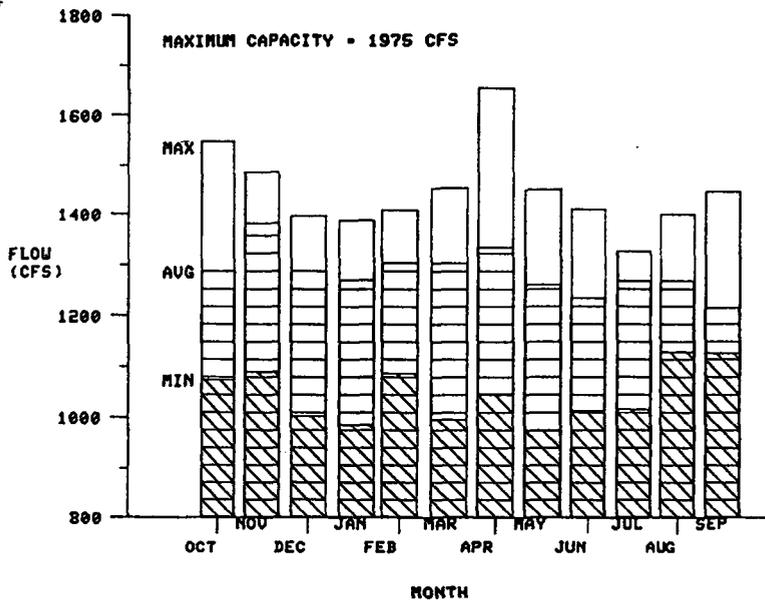


FIG. 6.—Average, Maximum, and Minimum Flow through Pear Blossom Pumping Plant (1922-1978)

output information for each aqueduct control point, supporting programs have been written to graphically display the information. This is shown in Fig. 6 where the average flow, maximum flow, and minimum flow are graphically summarized for each calendar month for the 57-yr simulation period at a particular aqueduct control point (Control Point 134 in Fig. 2).

SWP Energy Analysis.—The DWR Planning Simulation Model can be used for energy use and power generation planning studies. Expected future energy needs and uses can be estimated for future levels of development and operation through the use of historic flows adjusted for future levels of development, or stochastic inflows.

For surface reservoirs, the power plant characteristics along with minimum monthly energy generation requirements can be readily specified. Based on the releases made to meet downstream flow requirements, the monthly energy generation is computed. If the specified minimum energy generation is not achieved, an additional amount of water is released to ensure the minimum energy generation.

The simulation model accommodates all of the characteristics of the SWP pumping and generating plants along the California Aqueduct from the Delta to Lake Perris and Castaic Reservoirs. Assuming that each of these plants with the exception of San Luis Reservoir operates at a fixed head, the model computes the monthly energy used or generated at each plant.

Finally, the energy use associated with groundwater withdrawals can also be computed by supplying the depth to groundwater table or pump lift and the assumed pumping plant characteristics.

SUMMARY AND CONCLUSIONS

As developed, the DWR Simulation Model has been demonstrated to be an effective tool for water resources planning. The detailed monthly simulation model incorporates a complex system of surface and subsurface reservoirs, rivers, channels, power plants, and aqueducts. A large spectrum of legal, institutional, physical, and operational constraints are readily simulated. The model differentiates the operations of the Bureau's Central Valley Project and the Department's State Water Project so that the coordination agreement proposed by both agencies is carefully followed in the simulation studies. The model is capable of being used for several types of planning studies and may accommodate stochastic data inputs. The SWP demands have the flexibility of being adjusted to reflect wet or dry year effects as well as increases with time.

Further works are underway to replace the routing mechanism of the HEC-3 model by a standardized network flow algorithm. This replacement will enhance the capability of the model with the additional benefit of faster computer execution of the model.

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APPENDIX.—REFERENCES

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